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(54) Title: INTEGRATION OF ARRAY OF NON-ROD SHAPED OPTICAL ELEMENTS WITH ARRAY OF FIBERS IN A STRUCTURE AND ASSOCIATED METHODS

(57) Abstract: Arrays of non-rod shaped optical elements may be integrated with fiber arrays arranged in a positioning structure. The use of non-rod shaped optical elements allow the elements to be lithographically created already accurately aligned relative to one another. This also allows for simultaneous alignment of the array of optical elements with the array of fibers. The arrays may be one or two dimensional. The support structure for the fibers may be any desired structure. The fiber endfaces may be angled. The array of optical elements may include more than one substrate bonded together. Passive alignment features, including visual alignment mark and/or mechanical mating features, may be provided on the arrays.

INTEGRATION OF ARRAY OF NON-ROD SHAPED OPTICAL ELEMENTS WITH ARRAY OF FIBERS IN A STRUCTURE AND ASSOCIATED METHODS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention is directed to integrating an array of non-rod shaped optical array with an array of fibers positioned in a structure and associated methods. The arrays may be arranged along one or more dimensions.

Description of Related Art

Numerous recent applications, such as optical switching, require precise positioning of fibers in an array. Such precise positioning is typically achieved using V-grooves in a substrate which can be accurately formed and in which the fibers are then placed to align them both vertically and horizontally with respect to one another. Typically, when using optical elements in conjunction with fibers in V-grooves, these optical elements are in the form of a rod, such as a Gradient Index (GRIN) lens. The use of such a lens allows V-grooves to also be employed to align these lenses with the fibers.

While GRIN lenses offer good performance, the individual insertion required to align each GRIN lens with a respective fiber is tedious and impractical on a large scale, especially as the industry moves toward two-dimensional arrays. While a two-dimensional bundle of optical elements other than rod-shaped elements have been used in conjunction with a two dimensional bundle of fibers for imaging applications, in which all of the fibers and optical elements are forming a single image, the alignment and positioning of the fibers is not nearly as demanding as that of the optical interconnection applications. Further, since all of the fibers are forming the same image, the fibers are arranged in a bundle as close together as possible, and would not be placed in the structure used for the accurate positioning of the fibers for optical interconnection

applications.

Thus, while the provision of one and two-dimensional array of fibers accurately arranged in structures has been realized, non-rod optical elements integrated therewith have not. Such non-rod elements are typically thinner, cheaper and an entire array of these elements may be of unitary construction for simultaneous alignment.

SUMMARY OF THE INVENTION

The present invention is therefore directed to integrating an array of non-rod shaped optical elements with an array of fibers positioned in structures and associated methods which substantially overcomes one or more of the problems due to the limitations and disadvantages of the related art.

These and other objects of the present invention will become more readily apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating the preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, aspects and advantages will be described with reference to the drawings, in which:

Fig. 1A is a perspective elevational view of a one-dimensional array of non-rod optical elements;

Fig. 1B is a perspective elevational view of a back side of one-dimensional array of non-rod optical elements shown in Fig. 1A;

Fig. 1C is a perspective elevational view of a one-dimensional array of fibers positioned in V-grooves;

Fig. 1D is an exploded perspective elevational view of the array of Fig. 1C;

Fig. 1E is a perspective elevational view of the integrated one-dimensional arrays of Figs. 1A and 1C;

Fig. 2A is a perspective elevational view of a one-dimensional array of non-rod optical elements;

Fig. 2B is a perspective elevational view of a spacer;

Fig. 2C is a perspective elevational view of a one-dimensional array of fibers positioned in V-grooves;

Fig. 2D is an exploded perspective elevational view of the array of Fig. 2C;

Fig. 2E is a perspective elevational view of the integrated one-dimensional arrays of Figs. 2A and 2C with the spacer of Fig. 2B;

Fig. 3A is a perspective elevational view of a one-dimensional array of non-rod optical elements;

Fig. 3B is a perspective elevational view of a one-dimensional array of fibers positioned in V-grooves;

Fig. 3C is an exploded perspective elevational view of the array of Fig. 3B;

Fig. 3D is a perspective elevational view of the integrated one-dimensional arrays of Figs. 3A and 3B;

Fig. 4A is a perspective elevational view of a one-dimensional array of non-rod optical elements;

Fig. 4B is a perspective elevational view of a one-dimensional array of fibers positioned in V-grooves;

Fig. 4C is an exploded perspective elevational view of the array of Fig. 4B;

Fig. 4D is a perspective elevational view of the integrated one-dimensional arrays of Figs. 4A and 4B;

Fig. 4E is a cross-section of the interface shown in Fig. 4D;

Fig. 4F is a cross-section of an alternative interface for fibers with angled endfaces;

Fig. 4G is a cross-section of a two-dimensional configuration of Fig. 4F;

Fig. 4H is a cross-section of another alternative interface for fibers with angled endfaces;

Fig. 5A is a perspective elevational view of a two-dimensional array of non-rod optical elements;

Fig. 5B is a perspective elevational view of a two-dimensional array of fibers positioned in V-grooves;

Fig. 5C is an exploded perspective elevational view of the array of Fig. 5B;

Fig. 5D is a perspective elevational view of the integrated two-dimensional arrays of Figs. 5A and 5B;

Fig. 6A is a perspective elevational view of two one-dimensional arrays of non-rod optical elements;

Fig. 6B is a perspective elevational view of a two-dimensional array of fibers positioned in V-grooves;

Fig. 6C is an exploded perspective elevational view of the array of Fig. 6B;

Fig. 6D is a perspective elevational view of the integrated arrays of Figs. 6A and 6B;

Fig. 7A is a perspective elevational view of a two-dimensional array of non-rod optical elements;

Fig. 7B is a perspective elevational view of two one-dimensional arrays of fibers positioned in V-grooves;

Fig. 7C is an exploded perspective elevational view of the arrays of Fig. 7B;

Fig. 7D is a perspective elevational view of the integrated arrays of Figs. 7A and 7B;

Fig. 8A is a perspective elevational view of a two-dimensional array of non-rod optical elements;

Fig. 8B is a perspective elevational view of two-dimensional array of holes in a substrate;

Fig. 8C is a perspective elevational view of the fibers arranged in a two-dimensional array;

Fig. 8D is a perspective elevational view of the integrated arrays of Figs. 8A-8C;

Fig. 9A is a cross-section of an alternative to using v-grooves in accordance with the present invention; and

Fig. 9B is a cross-section of another embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be described in detail through preferred embodiments with reference to accompanying drawings. However, the present invention is not limited to the following embodiments but may be implemented in various types. The preferred embodiments are only provided to make the disclosure of the invention complete and make one having an ordinary skill in the art know the scope of the invention. The thicknesses of various layers and regions are emphasized for clarity in accompanying drawings.

Figures 1A-1D illustrate the simplest configuration of the present invention. Figure 1A is a one-dimensional array 100 of non-rod optical elements 104 formed on a substrate 102. This array 100 is unitary. This array 100 may be formed on a wafer level, e.g., photolithographicaly, and then diced to formed a desired one-dimensional array. The optical elements may be of refractive elements, diffractive elements or hybrids thereof. The elements 104 of the array 100 do not have to be the same. The elements 104 may perform any desired optical function or combinations thereof, such as collimating, focusing, homogenizing, etc. The elements 104 are spaced in accordance with the fiber spacing in a one-dimensional array 108 of fibers 106 shown in Figures 1C and 1D.

As can be seen in Figures 1B and 1C, the one-dimensional array 108 of fibers 106 includes an array of upper V-grooves 110 in an upper substrate 112 and an array of lower V-grooves 114 in a lower substrate 116. The fibers 106 are placed in respective V-grooves 110, 114 which are aligned with one another. The substrates 112, 116 are then adhered to one another in a conventional manner.

The one-dimensional array 100 and the one-dimensional array 108 are aligned and adhered to form the integrated optics-fiber structure 118 as shown in Figure 1D. The alignment may be performed actively, with light traveling through the elements, or passively. While passive alignment features may be provided on the one-dimensional array 100 of optical elements 104, since the V-grooves 110, 114 are typically formed by dicing a substrate containing longer V-grooves, such alignment features are not readily formed thereon. However, since the V-grooves 110, 114 can be so precisely formed, for example by anisotropic etching on a semiconductor substrate, such as a silicon substrate, the V-grooves 110, 114 themselves may be used as the passive alignment features for aligning the optics 104 and the fibers 106. Thus, the alignment features on the one-dimensional array 100 will be for passively aligning, either visually or mechanically, with the corresponding V-grooves 110, 114 of the one-dimensional array 108.

The visual alignment features may include optical fiducial marks, while the mechanical mating features may include protrusions 103 shown in Figure 1B on a surface of the array 100 facing the fiber array, such that these protrusions 103 fit into the empty space in the v-groove 110 above and/or below the fiber. When the optical elements are lithographically formed, it is advantageous to create the alignment features lithographically as well. The lithographic creation of the alignment features may be with the same mask used for creation of the optical elements, or with another mask.

The configuration shown in Figures 2A-2E is similar to that of Figures 1A-1E, as indicated by the use of the same reference numerals for the same elements. Therefore, additional description of these elements will be eliminated. As shown in Figures 2B and 2E, the present configuration includes a spacer 201, e.g., a transparent spacer or a hollow spacer providing empty space in a region in which light is to travel between the optics and the fiber. When using a hollow spacer, the desired beam size to be realized in a shorter distance, since the light to or from the fiber will converge or diverge faster in free space than in a medium.

The configuration shown in Figures 3A-3E is similar to that of Figures 2A-2E, as indicated by the use of the same reference numerals for the same elements. Therefore, additional description of these elements will not be reiterated. As shown in Figures 3A and 3E, the one-dimensional array 300 in addition to the previous optical elements 104, includes optical elements 304 which are used exclusively for alignment. By providing alignment features 306 on a surface where an optical element should be, passive alignment of the one-dimensional array 300 may be realized by aligning the alignment marks 306 on the periphery of the array 300 with a corresponding fiber 106. The corresponding channel will not be used in the end application. Such passive alignment is particularly useful when the positioning structure for the fibers 106 does not include V-grooves or other features which may be used for alignment on the end face of the structure, for example, when precisely formed holes in which the fibers 106 are inserted are used to precisely position the fibers.

The configuration in Figures 4A-4D illustrate how the optics and fiber may be integrated when the endfaces of the fibers are at an angle. Angled endfaces help reduce back reflections, and the losses associated therewith.

As shown in Figure 4A, the one-dimensional array 400 includes a substrate 402 having non-rod optical elements 404 therein. These optical elements 404 are refractive elements, they are no longer circular as in the other examples, but now are elliptical to match the shape of the fiber endfaces. Further, the optical elements 404 are preferably diffractive elements which compensate for the shape of the light output by the angled fiber.

As can be seen in Figures 4B and 4C, the one-dimensional array 408 of fibers 406 having angled endfaces 407 includes an array of upper V-grooves 410 in an upper substrate 412 and an array of lower V-grooves 414 in a lower substrate 416. As before, the fibers 406 are placed in respective V-grooves 410, 414 which are aligned with one

another and the substrates 412, 416 are then adhered to one another in a conventional manner. However, the substrates 412, 416 also have angled endfaces 413, 417 in accordance with the angle of the fiber endfaces 407.

The one-dimensional array 400 and the one-dimensional array 408 are aligned and adhered to form an integrated optics-fiber structure 418. The alignment may be performed as discussed above. Since the one-dimensional array 400 of the elliptical optical elements 404 is still formed from a flat wafer, an endface 419 of the integrated optics-fiber structure 418 is still angled in accordance with the angle of the fiber endface 407.

A better view of the interface between the optics block and the angled fiber is seen in Fig. 4E. Since the beam coming out of the angled fiber endface is elliptical, the optical elements 404 are anamorphic to collimate the beam. However, since the optics block is tilted, the beam is still tilted. Further, mounting the optics block at an angle is more difficult than straight.

An alternative embodiment is shown in Fig. 4F. Here, the lens array block 420 is kept straight, while support elements 422, 424 are provided on either side of the support structure for the fiber 406, e.g., the v-groove block 408. These support elements 422, 424, serve as a mount for the optics block 400. This configuration is advantageous for two-dimensional arrays, as shown in Fig. 4G, where two fibers 406 forming a two dimensional array, with additional fibers being in the plane of the page above and below the representative fibers . The intermediate support structure between the upper and lower fibers is indicated at 426. This configuration eliminates adhesive in the optical path, but does require more parts. Further, the use of an anamorphic lens on the flat surface now removes tilt from the beam. While the angle here is exaggerated for illustration, the angle of the endface of the fiber is typically about 8°-12° perpendicular to the optical axis of the fiber.

Another configuration is shown in Fig. 4G, in which the optics block 430 has one surface thereof sloped to match the angle of the fiber endface, while another surface thereof is orthogonal to the fiber axis. Thus, the surfaces of the optics block 430 are not parallel. However, since the angle of the fiber endface is relatively small, the difference in distance traveled by the beam does not significantly affect the output. This configuration corrects for the tilt as well. If optical elements are only formed on the straight surface, the angle on the other surface may be formed by polishing that surface after formation of the elements.

A configuration for two-dimensional arrays is shown in Figures 5A-5D. Figure 5A is a two-dimensional array 500 of non-rod optical elements 504 formed on a substrate 502. This array 500 may be formed on a wafer level and then diced to formed a desired two-dimensional array which contains at least two rows and at least two columns of optical elements. This array 500 in unitary. The array 500 may be of refractive elements, diffractive elements or hybrids thereof. The elements 504 of the array 500 do not have to be the same. The elements 504 are spaced in accordance with the fiber spacing in a two-dimensional array 508 of fibers 506 shown in Figures 5B and 5C.

As can be seen in Figures 5B and 5C, the two-dimensional array 508 of fibers 506 includes an upper V-groove 510 in an upper substrate 512 and a lower V-groove 514 in a lower substrate 516. The two-dimensional array 508 also includes an upper middle V-groove 520 and a lower middle V-groove 522, both of which are in a middle substrate 524. An upper row of fibers 506 are placed in respective V-grooves 510, 520, and a lower row of fibers 506 are placed in respective V-grooves 514, 522. All of these V-grooves 510, 514, 520, 522 are aligned with one another and the substrates 512, 516, 524 are then adhered to one another in a conventional manner. Obviously, numerous middle substrates could be provided to accommodate any desired number of rows of fibers.

The two-dimensional array 500 and the two-dimensional array 508 are aligned and adhered to form the integrated optics-fiber structure 518 as shown in Figure 5D. The

alignment may be performed as discussed above.

However, alignment of two-dimensional arrays is more difficult than alignment of one-dimensional arrays. Therefore, it is advantageous to deconstruct at least one of two into a plurality of one-dimensional arrays. As used herein, "deconstructed"is to mean each array, typically a one-dimensional array, of the deconstructed array may be aligned independently from each other.

As shown in Figures 6A-6D, instead of providing a two-dimensional array 500, a deconstructed two-dimensional array 600 having two one-dimensional arrays 100 of optical elements 104 is provided. The structure of the fiber array 508 is similar to that of Figures 5B-5C, as indicated by the use of the same reference numerals for the same elements, and has not been reiterated.

Now when aligning the two-dimensional arrays 600, 508 to form the integrated optics-fiber structure 618 shown in Figure 6D, any deviation in the thickness of the middle substrate 524 from a desired thickness may be compensated. Further, the use of the deconstructed two-dimensional array 600 is particularly advantageous when the fibers in different rows are to be offset from one another.

As shown in Figures 7A-7D, instead of providing a two-dimensional array 508, a deconstructed two-dimensional array 708 having two one-dimensional arrays of fibers 706 is provided as shown in Figures 7B and 7C. The structure of the two-dimensional array 500 is similar to that of Figure 5A, as indicated by the use of the same reference numerals for the same elements, and has not been reiterated.

As can be seen in Figures 7B and 7C, the deconstructed two-dimensional array 708 of fibers 706 includes an array of upper V-grooves 710 in an upper substrate 712 and an array of lower V-grooves 714 in a lower substrate 716. The deconstructed two-

dimensional array 708 also includes an array of upper middle V-grooves 720 formed in an upper middle substrate 721 and an array of lower middle V-grooves 722 formed in a lower middle substrate 723. An upper row of fibers 706 are placed in respective V-grooves 710, 720, and a lower row of fibers 706 are placed in respective V-grooves 714, 722. The V-grooves 710, 720 are aligned with one another and the substrates 712 and 721 are then adhered to one another in a conventional manner. Similarly, the V-grooves 714, 722 are aligned with one another and the substrates 716 and 723 are then adhered to one another in a conventional manner. Obviously, numerous middle substrates could be provided to accommodate any desired number of rows of fibers.

Now when aligning the two-dimensional arrays 500, 708 to form the integrated optics-fiber structure 718 shown in Figure 7D, any deviation in the vertical separation of the optical elements 504 from a desired separation may be compensated.

The configuration shown in Figures 8A-8D, holes 811 in a substrate 812 are used instead of V-grooves to accurately position and house the fibers 106 therein to form the integrated optics-fiber structure 818 shown in Figure 8D. Otherwise, the structure is similar to that of Figures 5A-5D, as indicated by the use of the same reference numerals for the same elements, and has not been reiterated. These holes may be drilled or may be formed lithographically. Of course, the substrate 813 with holes 811could be used with any of the above configurations. When holes are used, a potential mechanical mating feature would be to provide rods extending from the array 500 for insertion into one of the holes 811 to facilitate alignment.

Another alternative to v-grooves is shown in Figs. 9A and 9B. As shown therein, a polymer film 902 is provided on the optics block 900 having the optical elements 904 thereon. The polymer film 902 may be a single layer or a plurality of layers. The polymer film 902 includes a plurality of holes 903 which align the fibers 906 to the optics block 900. The holes 903 may be formed lithographically in the polymer layer using the same

alignment marks as used in creating the optics on the optics block 900. This reduces the requirements on the support structure for the fibers 906, since these fibers are now aligned by the holes in the polymer film. The fibers may be tapered to further facilitate the alignment in the holes and the loose alignment in the support. Fig. 9B illustrates another alternative of the configuration in Fig. 9A in which there are two substrates, 900, 908, each which may have optical elements thereon. The substrates may be bonded together. Any of the previous configurations may include the use of a plurality of substrates bonded together, and optical elements may be provided on either side of the substrate(s).

While all of the example of two-dimensional arrays used fibers with flat endfaces, no spacers, and circular optical elements alone, any of the arrays discussed in connection with the one-dimensional arrays could be employed in any of the two-dimensional configurations. Further, when forming a two-dimensional array, a plurality of one-dimensional arrays could be used for both the optical elements and the fibers, e.g., by integrating array 600 with array 708. Additionally, while the configurations show the fibers in V-grooves or holes, any structure for providing precise positioning of the fibers may be used. Anti-reflection coatings may be provided wherever needed. Finally, either active and/or passive alignment, either visual and/or mechanical, may be used with any of the configurations.

While the present invention is described herein with reference to illustrative embodiments for particular applications, it should be understood that the present invention is not limited thereto. Those having ordinary skill in the art and access to the teachings provided herein will recognize additional modifications, applications, and embodiments within the scope thereof and additional fields in which the invention would be of significant utility without undue experimentation. Thus, the scope of the invention should be determined by the appended claims and their legal equivalents, rather than by the examples given.

WHAT IS CLAIMED IS:

1. A system comprising:

an array of fibers arranged in a structure providing precise positioning of the fibers; and

an array of non-rod shaped optical elements, each optical element corresponding to a fiber, said array of non-rod shaped optical elements being integral with said array of fibers.

2. The system of claim 1, wherein said array of non-rod shaped optical elements is a unitary element.

3. The system of claim 1, wherein said non-rod shaped optical elements are lithographically created.

4. The system of claim 1, wherein said array of fibers and said array of non-rod shaped optical elements are two-dimensional arrays.

5. The system of claim 4, wherein one of said array of fibers and said array of non-rod shaped optical elements is a deconstructed two-dimensional array and another of said array of fibers and said array of non-rod shaped optical elements is an integrated two-dimensional array.

6. The system of claim 1, further comprising a spacer between said array of non-rod shaped optical elements and said array of fibers.

7. The system of claim 6, wherein said spacer is hollow in regions through which light is to pass between said array of non-rod shaped elements and said array of fibers.

8. The system of claim 6, wherein said spacer is transparent to wavelengths of

interest through which light is to pass between said array of non-rod shaped elements and said array of fibers.

9. The system of claim 1, wherein endfaces of fibers in said array of fibers are angled and a cross-section of non-rod shaped optical elements is matched to a cross-section of the endfaces.

10. The system of claim 2, wherein endfaces of fibers in said array of fibers are angled and the unitary element of optical elements includes an angled face to match the fiber endfaces at an interface therebetween.

11. The system of claim 10, wherein a face of the unitary element opposite the interface is parallel to the angled face.

12. The system of claim 10, wherein a face of the unitary element opposite the interface is orthogonal to a fiber axis.

13. The system of claim 1, wherein endfaces of fibers in said array of fibers are angled and said non-rod shaped optical elements reduces tilt in light output from said endfaces.

14. The system of claim 1, wherein endfaces of fibers in said array of fibers are angled and the system further comprises at least one support structure on at least one of a top and a bottom of said array of fibers, said support structure providing a mount for said non-rod shaped optical elements.

15. The system of claim 14, wherein said non-rod shaped optical elements are integrated into a unitary element, both faces of said unitary element being substantially orthogonal to a central axis of the system.

16. The system of claim 1, wherein said structure comprises a plurality of V-grooves, each V-groove receiving a corresponding fiber.

17. The system of claim 14, further comprising alignment features on a substrate supporting said array of non-rod shaped optical elements, said alignment features to be aligned with corresponding V-grooves of wherein said array of fibers and said array of non-rod shaped optical elements are two-dimensional arrays.

18. The system of claim 1, further comprising alignment marks positioned in at least one peripheral non-rod shaped optical element of said array of non-rod shaped optical elements.

19. The system of claim 1, wherein endfaces of fibers in said array of fibers are angled and said array of non-rod shaped optical elements include an anamorphic optical element.

20. The system of claim 1, wherein said anamorphic optical elements reduces tilt with respect to the fiber endface.

21. The system of claim 1, wherein said structure is a lithographically formed plurality of holes into which said array of fibers are inserted.

22. The system of claim 21, wherein said lithographically formed plurality of holes is in a polymer film deposited on a surface of a substrate.

23. The system of claim 2, wherein said unitary element includes a plurality of substrates bonded together.

24. The system of claim 1, wherein said array of optical elements includes lithographically created alignment features.

25. The system of claim 24, wherein lithographically created alignment features include at least one of visual fiducial marks and mechanical mating structures.

26. A method of integrating an array of fibers and an array of non-rod shaped optical elements comprising:

positioning the array of fibers in a corresponding array of precisely positioned housing features in a structure; and

aligning and bonding the array of non-rod shaped optical elements to the array of fibers.

27. The method of claim 26, providing an gap between the array of fibers and the array of non-rod shaped optical elements are two-dimensional arrays.

28. The method of claim 26, wherein providing includes inserting a spacer between the array of fibers and the array of non-rod shaped optical elements.

29. The method of claim 26, further comprising arranging the array of fibers and the array of non-rod shaped optical elements in two-dimensions.

30. The method of claim 29, wherein at least one of the array of fibers and the array of non-rod shaped optical elements comprises at least two one-dimensional arrays.

31. The method of claim 26, wherein said aligning includes forming passive alignment features on the array of non-rod shaped optical elements and aligning passive alignment features to the precisely positioned housing features.

32. The method of claim 26, further comprising, before said aligning, creating the array of non-rod shaped optical elements lithographically.

33. The method of claim 26, further comprising, before said aligning, creating non-rod shaped optical elements on a wafer and dicing the wafer to form the array of non-rod shaped optical elements.

34. The method of claim 32, further comprising, before said aligning, lithographically creating alignment features on the array of non-rod shaped optical elements.

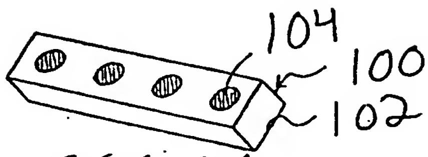

FIG. 1A

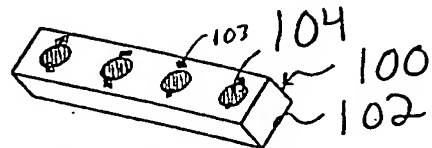

FIG. 1B

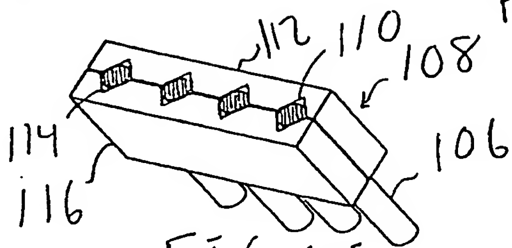

FIG. 1C

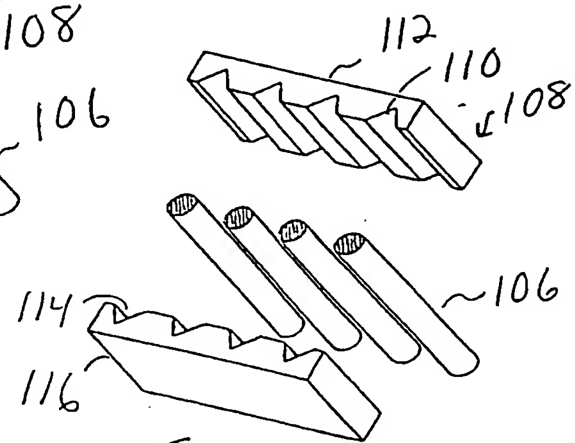

FIG. 1D

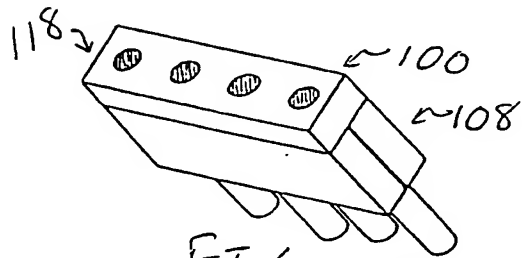

FIG. 1E

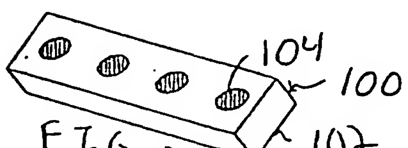

FIG. 2A

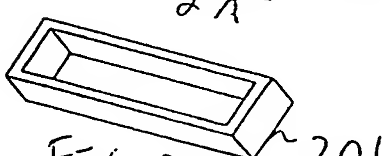

FIG. 2B

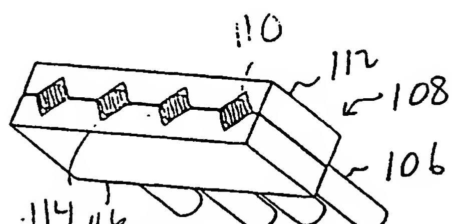

FIG. 2C

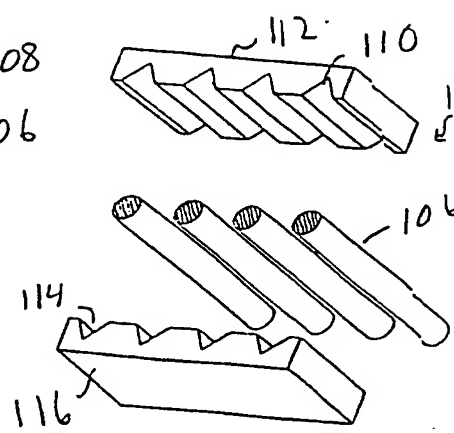

FIG. 2D

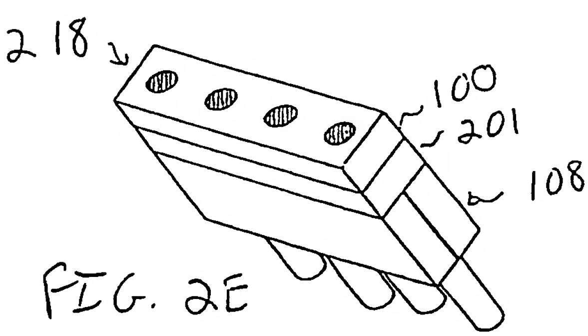

FIG. 2E

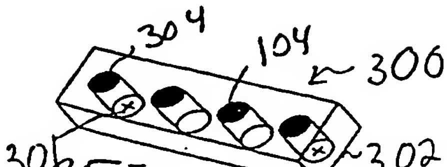

FIG. 3A

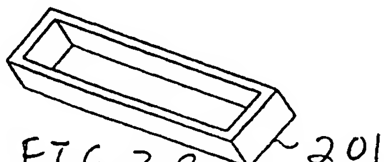

FIG. 3B

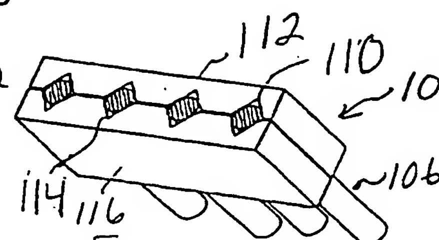

FIG. 3C

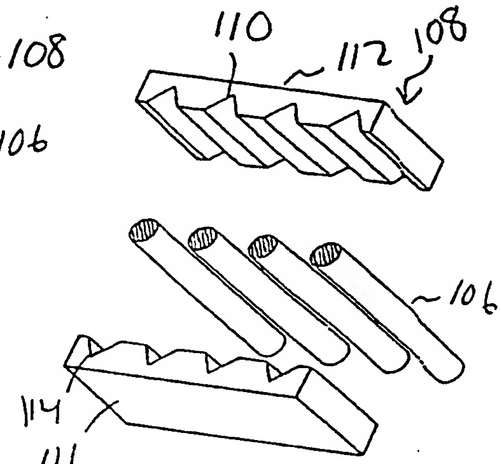

FIG. 3D

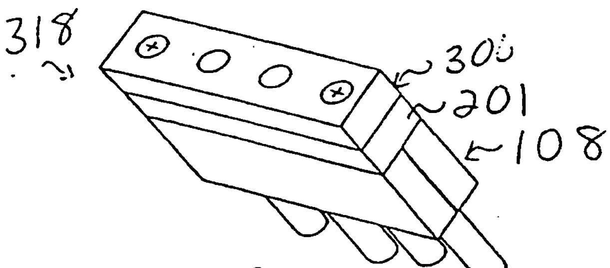

FIG. 3E

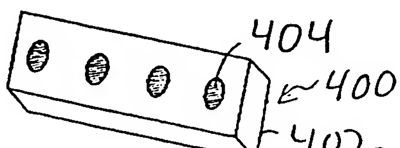

FIG. 4A

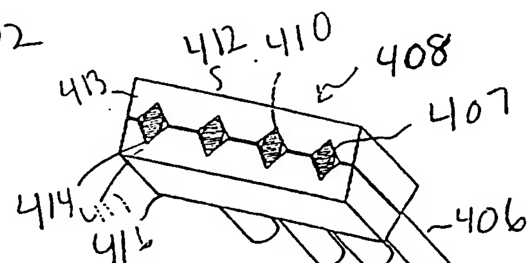

FIG. 4B

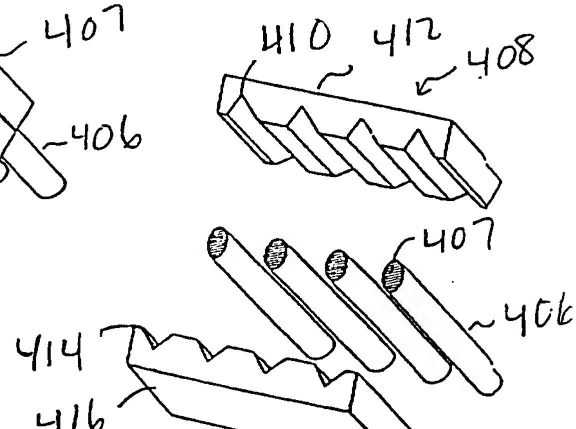

FIG. 4C

FIG. 4D

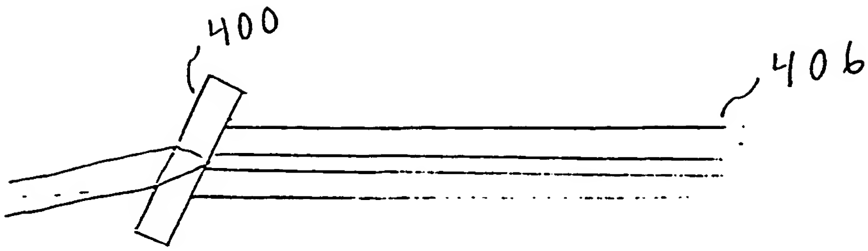

FIG. 4E

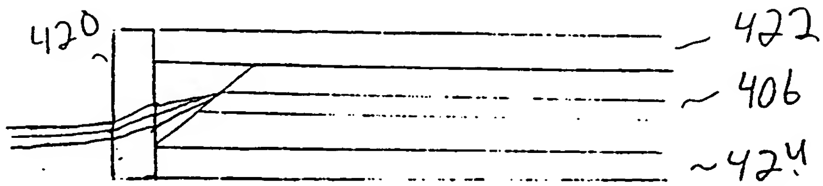

FIG. 4F

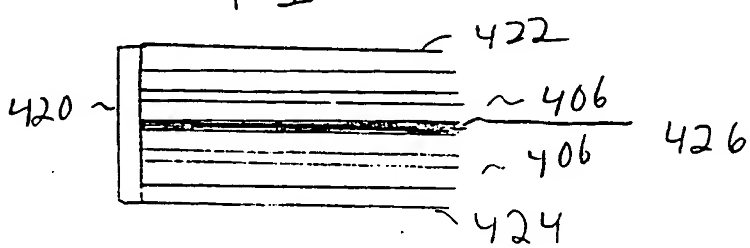

FIG. 4G

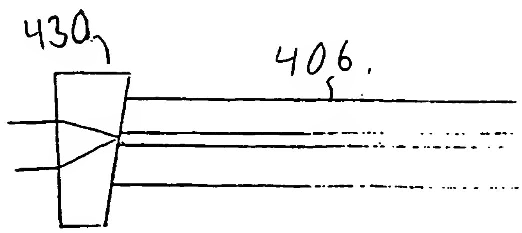

FIG. 4F

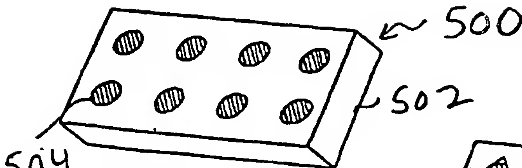

FIG. 5A

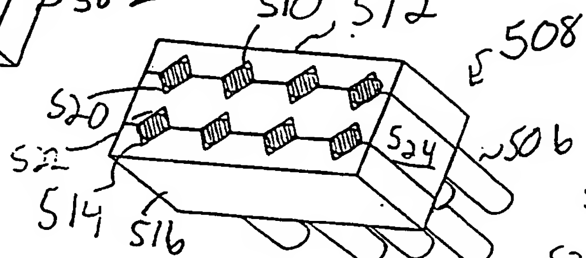

FIG. 5B

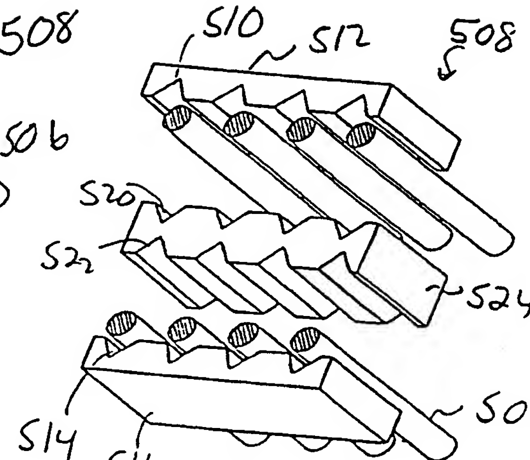

FIG. 5C

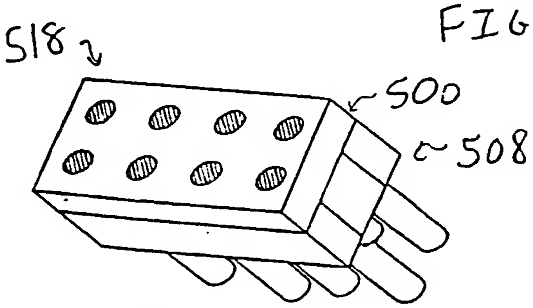

FIG. 5D

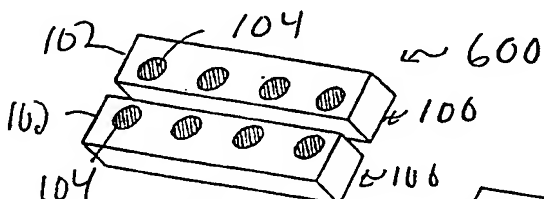

FIG. 6A

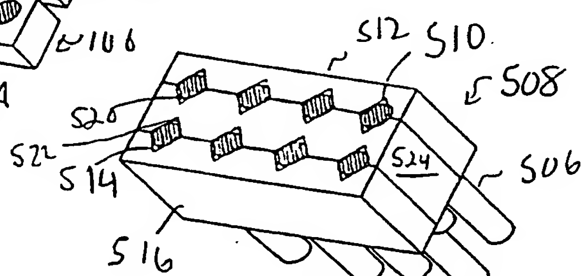

FIG. 6B

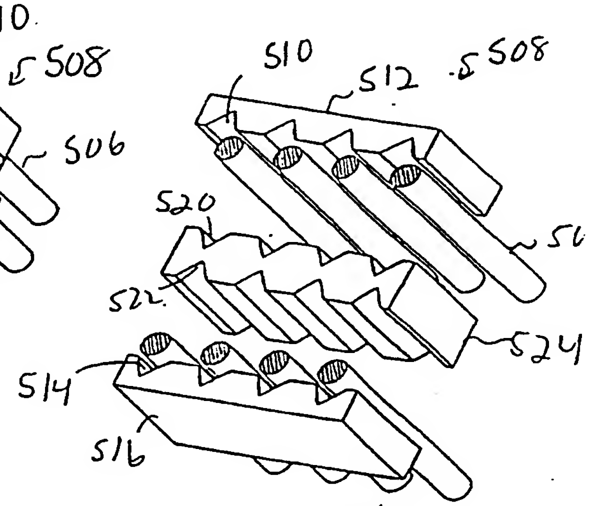

FIG. 6C

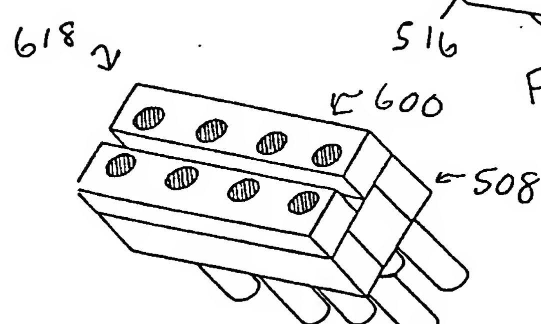

FIG. 6D

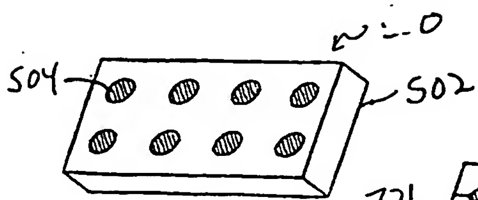

FIG. 7A

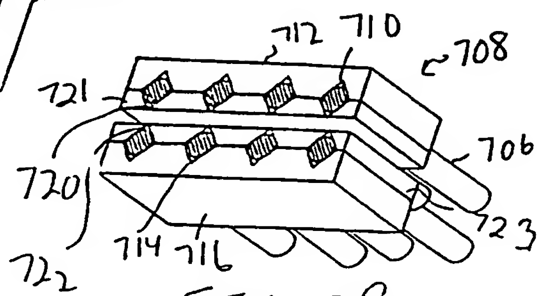

FIG 7B

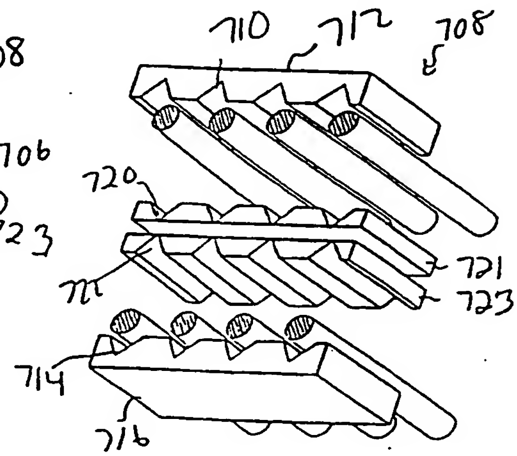

FIG. 7C

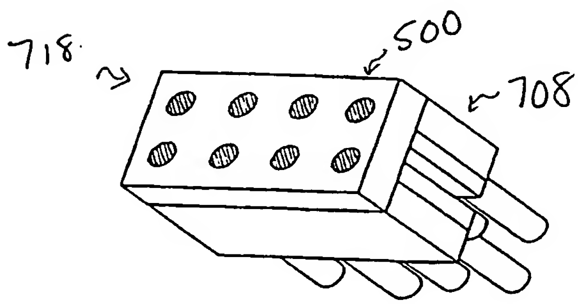

FIG. 7D

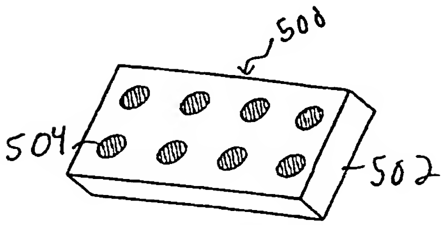

FIG. 8A

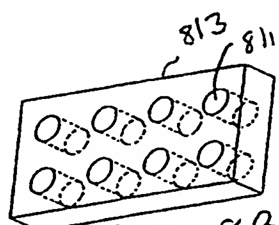

FIG. 8B

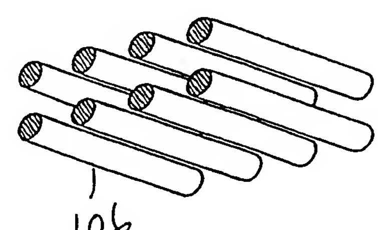

FIG. 8C

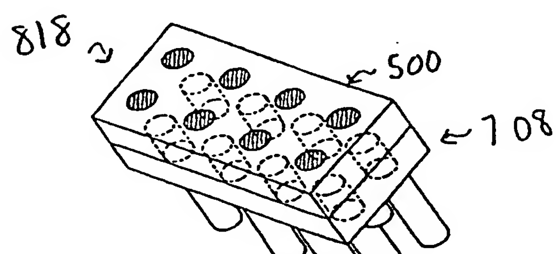

FIG. 8D

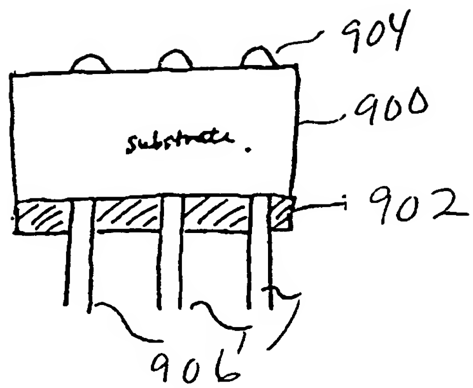
904
900
substrate
902
906

FIG. 9A

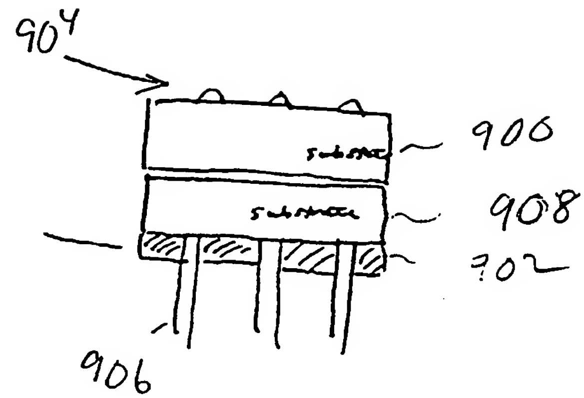
904
900
substrate
908
substrate
902
906

FIG. 9B

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
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(10) International Publication Number
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(51) International Patent Classification[7]: G02B 6/38, 6/42, 6/32

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60/163,574 5 November 1999 (05.11.1999) US

(71) Applicant (for all designated States except US): DIGITAL OPTICS CORPORATION [US/US]: Suite J, 5900 Northwoods Business Parkway, Charlotte, NC 28269 (US).

(72) Inventors; and
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(74) Agent: MORSE, Susan, S.: Digital Optics Corporation, Suite 150, 12200 Sunrise Valley Drive, Reston, VA 20191 (US).

(81) Designated States (national): AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
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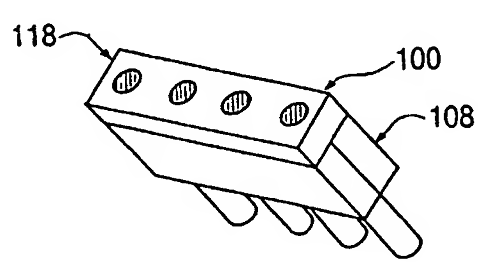
(88) Date of publication of the international search report: 10 January 2002

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: INTEGRATION OF ARRAY OF NON-ROD SHAPED OPTICAL WITH ARRAY OF OPTICAL FIBERS



(57) Abstract: Arrays (100) of non-rod shaped optical elements (104) may be integrated with fiber arrays (108) arranged in a positioning structure (110, 114). The use of non-rod shaped optical elements allow the elements to be lithographically created already accurately aligned relative to one another. This also allows for simultaneous alignment of the array of optical elements with the array of fibers. The arrays may be one or two dimensional. The support structure for the fibers may be any desired structure. The fiber endfaces may be angled. The array of optical elements may include more than one substrate bonded together. Passive alignment features, including visual alignment mark and/or mechanical mating features, may be provided on the arrays.

WO 01/33262 A3

INTERNATIONAL SEARCH REPORT

Inter. ›nal Application No
PCT/US 00/30431

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B6/38 G02B6/42 G02B6/32

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

PAJ, EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 014, no. 345 (P-1083), 26 July 1990 (1990-07-26) -& JP 02 123301 A (NIPPON SHEET GLASS CO LTD;OTHERS: 01), 10 May 1990 (1990-05-10) abstract; figures 1,2	1-4,21, 22,26, 29,32,33

X	PATENT ABSTRACTS OF JAPAN vol. 017, no. 428 (P-1588), 9 August 1993 (1993-08-09) & JP 05 088049 A (FUJITSU LTD), 9 April 1993 (1993-04-09) abstract	1,2,4,6, 8,23, 26-29

X	US 5 241 612 A (IWAMA TAKEO) 31 August 1993 (1993-08-31)	1,2,6-8, 26-28
Y	the whole document	9-15,17, 19,20

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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Date of the actual completion of the international search	Date of mailing of the international search report
3 May 2001	16/05/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Lord, R

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INTERNATIONAL SEARCH REPORT

Inter. ..nal Application No
PCT/US 00/30431

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	H. HAN ET AL: "Integration of Silicon Bench with Micro Optics" SPIE CONFERENCE ON PHOTONICS PACKAGING AND INTEGRATION, vol. 3631, January 1999 (1999-01), pages 234-243, XP000995170 San Jose, California page 236 -page 237 page 239 -page 240	1-3,16, 26,32,33
X	PATENT ABSTRACTS OF JAPAN vol. 1996, no. 07, 31 July 1996 (1996-07-31) & JP 08 075950 A (RICOH CO LTD), 22 March 1996 (1996-03-22) abstract	1,2,16, 24-26, 31,33,34
X	PATENT ABSTRACTS OF JAPAN vol. 1996, no. 03, 29 March 1996 (1996-03-29) -& JP 07 311320 A (HITACHI CABLE LTD;OTHERS: 01), 28 November 1995 (1995-11-28) abstract	1-3, 24-27, 31,33,34
Y		17,18
X	EP 0 619 505 A (NGK INSULATORS LTD) 12 October 1994 (1994-10-12) column 6, line 32 - line 37; figure 5 column 7, line 39 -column 8, line 34; figures 9-13	1,2,4,5, 16,26, 30,32
Y	EP 0 525 433 A (SIEMENS AG) 3 February 1993 (1993-02-03) the whole document	9-15, 17-20
Y	PATENT ABSTRACTS OF JAPAN vol. 018, no. 402 (P-1777), 27 July 1994 (1994-07-27) & JP 06 118283 A (RICOH CO LTD), 28 April 1994 (1994-04-28) abstract	14
Y	PATENT ABSTRACTS OF JAPAN vol. 017, no. 695 (E-1480), 20 December 1993 (1993-12-20) & JP 05 236216 A (RICOH CO LTD), 10 September 1993 (1993-09-10) abstract	19,20

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inter ⸺nal Application No
PCT/US 00/30431

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
JP 02123301	A	10-05-1990	JP	2719804	B	25-02-1998
JP 05088049	A	09-04-1993	NONE			
US 5241612	A	31-08-1993	JP	5072444	A	26-03-1993
JP 08075950	A	22-03-1996	NONE			
JP 07311320	A	28-11-1995	NONE			
EP 0619505	A	12-10-1994	JP	7005341	A	10-01-1995
			DE	69421432	D	09-12-1999
			DE	69421432	T	04-05-2000
			US	5446815	A	29-08-1995
EP 0525433	A	03-02-1993	NONE			
JP 06118283	A	28-04-1994	JP	3136205	B	19-02-2001
JP 05236216	A	10-09-1993	NONE			

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

CORRECTED VERSION

(19) World Intellectual Property Organization
International Bureau

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10 May 2001 (10.05.2001)

PCT

(10) International Publication Number
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(51) International Patent Classification[7]: G02B 6/38, 6/42, 6/32

(21) International Application Number: PCT/US00/30431

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(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/163,574 5 November 1999 (05.11.1999) US

(71) Applicant *(for all designated States except US)*: **DIGITAL OPTICS CORPORATION** [US/US]; Suite J, 5900 Northwoods Business Parkway, Charlotte, NC 28269 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **HAN, Hongtao** [US/US]; 204 Chandeleur Drive, Mooresville, NC 28117 (US). **FELDMAN, Michael** [—/US]; 3117 Lakewood Edge, Charlotte, NC 28269 (US).

(74) Agent: **MORSE, Susan, S.**; Digital Optics Corporation, Suite 150, 12200 Sunrise Valley Drive, Reston, VA 20191 (US).

(81) Designated States *(national)*: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

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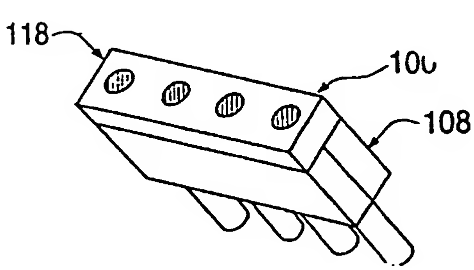
(54) Title: INTEGRATION OF ARRAY OF NON-ROD SHAPED OPTICAL WITH ARRAY OF OPTICAL FIBERS

WO 01/33262 A3



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INTEGRATION OF ARRAY OF NON-ROD SHAPED OPTICAL WITH ARRAY OF OPTICAL FIBERS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention is directed to integrating an array of non-rod shaped optical array with an array of fibers positioned in a structure and associated methods. The arrays may be arranged along one or more dimensions.

Description of Related Art

Numerous recent applications, such as optical switching, require precise positioning of fibers in an array. Such precise positioning is typically achieved using V-grooves in a substrate which can be accurately formed and in which the fibers are then placed to align them both vertically and horizontally with respect to one another. Typically, when using optical elements in conjunction with fibers in V-grooves, these optical elements are in the form of a rod, such as a Gradient Index (GRIN) lens. The use of such a lens allows V-grooves to also be employed to align these lenses with the fibers.

While GRIN lenses offer good performance, the individual insertion required to align each GRIN lens with a respective fiber is tedious and impractical on a large scale, especially as the industry moves toward two-dimensional arrays. While a two-dimensional bundle of optical elements other than rod-shaped elements have been used in conjunction with a two dimensional bundle of fibers for imaging applications, in which all of the fibers and optical elements are forming a single image, the alignment and positioning of the fibers is not nearly as demanding as that of the optical interconnection applications. Further, since all of the fibers are forming the same image, the fibers are arranged in a bundle as close together as possible, and would not be placed in the structure used for the accurate positioning of the fibers for optical interconnection

applications.

Thus, while the provision of one and two-dimensional array of fibers accurately arranged in structures has been realized, non-rod optical elements integrated therewith have not. Such non-rod elements are typically thinner, cheaper and an entire array of these elements may be of unitary construction for simultaneous alignment.

SUMMARY OF THE INVENTION

The present invention is therefore directed to integrating an array of non-rod shaped optical elements with an array of fibers positioned in structures and associated methods which substantially overcomes one or more of the problems due to the limitations and disadvantages of the related art.

These and other objects of the present invention will become more readily apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating the preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, aspects and advantages will be described with reference to the drawings, in which:

Fig. 1A is a perspective elevational view of a one-dimensional array of non-rod optical elements;

Fig. 1B is a perspective elevational view of a back side of one-dimensional array of non-rod optical elements shown in Fig. 1A;

Fig. 1C is a perspective elevational view of a one-dimensional array of fibers positioned in V-grooves;

Fig. 1D is an exploded perspective elevational view of the array of Fig. 1C;

Fig. 1E is a perspective elevational view of the integrated one-dimensional arrays of Figs. 1A and 1C;

Fig. 2A is a perspective elevational view of a one-dimensional array of non-rod optical elements;

Fig. 2B is a perspective elevational view of a spacer;

Fig. 2C is a perspective elevational view of a one-dimensional array of fibers positioned in V-grooves;

Fig. 2D is an exploded perspective elevational view of the array of Fig. 2C;

Fig. 2E is a perspective elevational view of the integrated one-dimensional arrays of Figs. 2A and 2C with the spacer of Fig. 2B;

Fig. 3A is a perspective elevational view of a one-dimensional array of non-rod optical elements;

Fig. 3B is a perspective elevational view of a one-dimensional array of fibers positioned in V-grooves;

Fig. 3C is an exploded perspective elevational view of the array of Fig. 3B;

Fig. 3D is a perspective elevational view of the integrated one-dimensional arrays of Figs. 3A and 3B;

Fig. 4A is a perspective elevational view of a one-dimensional array of non-rod optical elements;

Fig. 4B is a perspective elevational view of a one-dimensional array of fibers positioned in V-grooves;

Fig. 4C is an exploded perspective elevational view of the array of Fig. 4B;

Fig. 4D is a perspective elevational view of the integrated one-dimensional arrays of Figs. 4A and 4B;

Fig. 4E is a cross-section of the interface shown in Fig. 4D;

Fig. 4F is a cross-section of an alternative interface for fibers with angled endfaces;

Fig. 4G is a cross-section of a two-dimensional configuration of Fig. 4F;

Fig. 4H is a cross-section of another alternative interface for fibers with angled endfaces;

Fig. 5A is a perspective elevational view of a two-dimensional array of non-rod optical elements;

Fig. 5B is a perspective elevational view of a two-dimensional array of fibers positioned in V-grooves;

Fig. 5C is an exploded perspective elevational view of the array of Fig. 5B;

Fig. 5D is a perspective elevational view of the integrated two-dimensional arrays of Figs. 5A and 5B;

Fig. 6A is a perspective elevational view of two one-dimensional arrays of non-rod optical elements;

Fig. 6B is a perspective elevational view of a two-dimensional array of fibers positioned in V-grooves;

Fig. 6C is an exploded perspective elevational view of the array of Fig. 6B;

Fig. 6D is a perspective elevational view of the integrated arrays of Figs. 6A and 6B;

Fig. 7A is a perspective elevational view of a two-dimensional array of non-rod optical elements;

Fig. 7B is a perspective elevational view of two one-dimensional arrays of fibers positioned in V-grooves;

Fig. 7C is an exploded perspective elevational view of the arrays of Fig. 7B;

Fig. 7D is a perspective elevational view of the integrated arrays of Figs. 7A and 7B;

Fig. 8A is a perspective elevational view of a two-dimensional array of non-rod optical elements;

Fig. 8B is a perspective elevational view of two-dimensional array of holes in a substrate;

Fig. 8C is a perspective elevational view of the fibers arranged in a two-dimensional array;

Fig. 8D is a perspective elevational view of the integrated arrays of Figs. 8A-8C;

Fig. 9A is a cross-section of an alternative to using v-grooves in accordance with the present invention; and

Fig. 9B is a cross-section of another embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be described in detail through preferred embodiments with reference to accompanying drawings. However, the present invention is not limited to the following embodiments but may be implemented in various types. The preferred embodiments are only provided to make the disclosure of the invention complete and make one having an ordinary skill in the art know the scope of the invention. The thicknesses of various layers and regions are emphasized for clarity in accompanying drawings.

Figures 1A-1D illustrate the simplest configuration of the present invention. Figure 1A is a one-dimensional array 100 of non-rod optical elements 104 formed on a substrate 102. This array 100 is unitary. This array 100 may be formed on a wafer level, e.g., photolithographicaly, and then diced to formed a desired one-dimensional array. The optical elements may be of refractive elements, diffractive elements or hybrids thereof. The elements 104 of the array 100 do not have to be the same. The elements 104 may perform any desired optical function or combinations thereof, such as collimating, focusing, homogenizing, etc. The elements 104 are spaced in accordance with the fiber spacing in a one-dimensional array 108 of fibers 106 shown in Figures 1C and 1D.

As can be seen in Figures 1B and 1C, the one-dimensional array 108 of fibers 106 includes an array of upper V-grooves 110 in an upper substrate 112 and an array of lower V-grooves 114 in a lower substrate 116. The fibers 106 are placed in respective V-grooves 110, 114 which are aligned with one another. The substrates 112, 116 are then adhered to one another in a conventional manner.

The one-dimensional array 100 and the one-dimensional array 108 are aligned and adhered to form the integrated optics-fiber structure 118 as shown in Figure 1D. The alignment may be performed actively, with light traveling through the elements, or passively. While passive alignment features may be provided on the one-dimensional array 100 of optical elements 104, since the V-grooves 110, 114 are typically formed by dicing a substrate containing longer V-grooves, such alignment features are not readily formed thereon. However, since the V-grooves 110, 114 can be so precisely formed, for example by anisotropic etching on a semiconductor substrate, such as a silicon substrate, the V-grooves 110, 114 themselves may be used as the passive alignment features for aligning the optics 104 and the fibers 106. Thus, the alignment features on the one-dimensional array 100 will be for passively aligning, either visually or mechanically, with the corresponding V-grooves 110, 114 of the one-dimensional array 108.

The visual alignment features may include optical fiducial marks, while the mechanical mating features may include protrusions 103 shown in Figure 1B on a surface of the array 100 facing the fiber array, such that these protrusions 103 fit into the empty space in the v-groove 110 above and/or below the fiber. When the optical elements are lithographically formed, it is advantageous to create the alignment features lithographically as well. The lithographic creation of the alignment features may be with the same mask used for creation of the optical elements, or with another mask.

The configuration shown in Figures 2A-2E is similar to that of Figures 1A-1E, as indicated by the use of the same reference numerals for the same elements. Therefore, additional description of these elements will be eliminated. As shown in Figures 2B and 2E, the present configuration includes a spacer 201, e.g., a transparent spacer or a hollow spacer providing empty space in a region in which light is to travel between the optics and the fiber. When using a hollow spacer, the desired beam size to be realized in a shorter distance, since the light to or from the fiber will converge or diverge faster in free space than in a medium.

The configuration shown in Figures 3A-3E is similar to that of Figures 2A-2E, as indicated by the use of the same reference numerals for the same elements. Therefore, additional description of these elements will not be reiterated. As shown in Figures 3A and 3E, the one-dimensional array 300 in addition to the previous optical elements 104, includes optical elements 304 which are used exclusively for alignment. By providing alignment features 306 on a surface where an optical element should be, passive alignment of the one-dimensional array 300 may be realized by aligning the alignment marks 306 on the periphery of the array 300 with a corresponding fiber 106. The corresponding channel will not be used in the end application. Such passive alignment is particularly useful when the positioning structure for the fibers 106 does not include V-grooves or other features which may be used for alignment on the end face of the structure, for example, when precisely formed holes in which the fibers 106 are inserted are used to precisely position the fibers.

The configuration in Figures 4A-4D illustrate how the optics and fiber may be integrated when the endfaces of the fibers are at an angle. Angled endfaces help reduce back reflections, and the losses associated therewith.

As shown in Figure 4A, the one-dimensional array 400 includes a substrate 402 having non-rod optical elements 404 therein. These optical elements 404 are refractive elements, they are no longer circular as in the other examples, but now are elliptical to match the shape of the fiber endfaces. Further, the optical elements 404 are preferably diffractive elements which compensate for the shape of the light output by the angled fiber.

As can be seen in Figures 4B and 4C, the one-dimensional array 408 of fibers 406 having angled endfaces 407 includes an array of upper V-grooves 410 in an upper substrate 412 and an array of lower V-grooves 414 in a lower substrate 416. As before, the fibers 406 are placed in respective V-grooves 410, 414 which are aligned with one

another and the substrates 412, 416 are then adhered to one another in a conventional manner. However, the substrates 412, 416 also have angled endfaces 413, 417 in accordance with the angle of the fiber endfaces 407.

The one-dimensional array 400 and the one-dimensional array 408 are aligned and adhered to form an integrated optics-fiber structure 418. The alignment may be performed as discussed above. Since the one-dimensional array 400 of the elliptical optical elements 404 is still formed from a flat wafer, an endface 419 of the integrated optics-fiber structure 418 is still angled in accordance with the angle of the fiber endface 407.

A better view of the interface between the optics block and the angled fiber is seen in Fig. 4E. Since the beam coming out of the angled fiber endface is elliptical, the optical elements 404 are anamorphic to collimate the beam. However, since the optics block is tilted, the beam is still tilted. Further, mounting the optics block at an angle is more difficult than straight.

An alternative embodiment is shown in Fig. 4F. Here, the lens array block 420 is kept straight, while support elements 422, 424 are provided on either side of the support structure for the fiber 406, e.g., the v-groove block 408. These support elements 422, 424, serve as a mount for the optics block 400. This configuration is advantageous for two-dimensional arrays, as shown in Fig. 4G, where two fibers 406 forming a two dimensional array, with additional fibers being in the plane of the page above and below the representative fibers . The intermediate support structure between the upper and lower fibers is indicated at 426. This configuration eliminates adhesive in the optical path, but does require more parts. Further, the use of an anamorphic lens on the flat surface now removes tilt from the beam. While the angle here is exaggerated for illustration, the angle of the endface of the fiber is typically about 8°-12° perpendicular to the optical axis of the fiber.

Another configuration is shown in Fig. 4G, in which the optics block 430 has one surface thereof sloped to match the angle of the fiber endface, while another surface thereof is orthogonal to the fiber axis. Thus, the surfaces of the optics block 430 are not parallel. However, since the angle of the fiber endface is relatively small, the difference in distance traveled by the beam does not significantly affect the output. This configuration corrects for the tilt as well. If optical elements are only formed on the straight surface, the angle on the other surface may be formed by polishing that surface after formation of the elements.

A configuration for two-dimensional arrays is shown in Figures 5A-5D. Figure 5A is a two-dimensional array 500 of non-rod optical elements 504 formed on a substrate 502. This array 500 may be formed on a wafer level and then diced to formed a desired two-dimensional array which contains at least two rows and at least two columns of optical elements. This array 500 in unitary. The array 500 may be of refractive elements, diffractive elements or hybrids thereof. The elements 504 of the array 500 do not have to be the same. The elements 504 are spaced in accordance with the fiber spacing in a two-dimensional array 508 of fibers 506 shown in Figures 5B and 5C.

As can be seen in Figures 5B and 5C, the two-dimensional array 508 of fibers 506 includes an upper V-groove 510 in an upper substrate 512 and a lower V-groove 514 in a lower substrate 516. The two-dimensional array 508 also includes an upper middle V-groove 520 and a lower middle V-groove 522, both of which are in a middle substrate 524. An upper row of fibers 506 are placed in respective V-grooves 510, 520, and a lower row of fibers 506 are placed in respective V-grooves 514, 522. All of these V-grooves 510, 514, 520, 522 are aligned with one another and the substrates 512, 516, 524 are then adhered to one another in a conventional manner. Obviously, numerous middle substrates could be provided to accommodate any desired number of rows of fibers.

The two-dimensional array 500 and the two-dimensional array 508 are aligned and adhered to form the integrated optics-fiber structure 518 as shown in Figure 5D. The

alignment may be performed as discussed above.

However, alignment of two-dimensional arrays is more difficult than alignment of one-dimensional arrays. Therefore, it is advantageous to deconstruct at least one of two into a plurality of one-dimensional arrays. As used herein, “deconstructed”is to mean each array, typically a one-dimensional array, of the deconstructed array may be aligned independently from each other.

As shown in Figures 6A-6D, instead of providing a two-dimensional array 500, a deconstructed two-dimensional array 600 having two one-dimensional arrays 100 of optical elements 104 is provided. The structure of the fiber array 508 is similar to that of Figures 5B-5C, as indicated by the use of the same reference numerals for the same elements, and has not been reiterated.

Now when aligning the two-dimensional arrays 600, 508 to form the integrated optics-fiber structure 618 shown in Figure 6D, any deviation in the thickness of the middle substrate 524 from a desired thickness may be compensated. Further, the use of the deconstructed two-dimensional array 600 is particularly advantageous when the fibers in different rows are to be offset from one another.

As shown in Figures 7A-7D, instead of providing a two-dimensional array 508, a deconstructed two-dimensional array 708 having two one-dimensional arrays of fibers 706 is provided as shown in Figures 7B and 7C. The structure of the two-dimensional array 500 is similar to that of Figure 5A, as indicated by the use of the same reference numerals for the same elements, and has not been reiterated.

As can be seen in Figures 7B and 7C, the deconstructed two-dimensional array 708 of fibers 706 includes an array of upper V-grooves 710 in an upper substrate 712 and an array of lower V-grooves 714 in a lower substrate 716. The deconstructed two-

dimensional array 708 also includes an array of upper middle V-grooves 720 formed in an upper middle substrate 721 and an array of lower middle V-grooves 722 formed in a lower middle substrate 723. An upper row of fibers 706 are placed in respective V-grooves 710, 720, and a lower row of fibers 706 are placed in respective V-grooves 714, 722. The V-grooves 710, 720 are aligned with one another and the substrates 712 and 721 are then adhered to one another in a conventional manner. Similarly, the V-grooves 714, 722 are aligned with one another and the substrates 716 and 723 are then adhered to one another in a conventional manner. Obviously, numerous middle substrates could be provided to accommodate any desired number of rows of fibers.

Now when aligning the two-dimensional arrays 500, 708 to form the integrated optics-fiber structure 718 shown in Figure 7D, any deviation in the vertical separation of the optical elements 504 from a desired separation may be compensated.

The configuration shown in Figures 8A-8D, holes 811 in a substrate 812 are used instead of V-grooves to accurately position and house the fibers 106 therein to form the integrated optics-fiber structure 818 shown in Figure 8D. Otherwise, the structure is similar to that of Figures 5A-5D, as indicated by the use of the same reference numerals for the same elements, and has not been reiterated. These holes may be drilled or may be formed lithographically. Of course, the substrate 813 with holes 811could be used with any of the above configurations. When holes are used, a potential mechanical mating feature would be to provide rods extending from the array 500 for insertion into one of the holes 811 to facilitate alignment.

Another alternative to v-grooves is shown in Figs. 9A and 9B. As shown therein, a polymer film 902 is provided on the optics block 900 having the optical elements 904 thereon. The polymer film 902 may be a single layer or a plurality of layers. The polymer film 902 includes a plurality of holes 903 which align the fibers 906 to the optics block 900. The holes 903 may be formed lithographically in the polymer layer using the same

alignment marks as used in creating the optics on the optics block 900. This reduces the requirements on the support structure for the fibers 906, since these fibers are now aligned by the holes in the polymer film. The fibers may be tapered to further facilitate the alignment in the holes and the loose alignment in the support. Fig. 9B illustrates another alternative of the configuration in Fig. 9A in which there are two substrates, 900, 908, each which may have optical elements thereon. The substrates may be bonded together. Any of the previous configurations may include the use of a plurality of substrates bonded together, and optical elements may be provided on either side of the substrate(s).

While all of the example of two-dimensional arrays used fibers with flat endfaces, no spacers, and circular optical elements alone, any of the arrays discussed in connection with the one-dimensional arrays could be employed in any of the two-dimensional configurations. Further, when forming a two-dimensional array, a plurality of one-dimensional arrays could be used for both the optical elements and the fibers, e.g., by integrating array 600 with array 708. Additionally, while the configurations show the fibers in V-grooves or holes, any structure for providing precise positioning of the fibers may be used. Anti-reflection coatings may be provided wherever needed. Finally, either active and/or passive alignment, either visual and/or mechanical, may be used with any of the configurations.

While the present invention is described herein with reference to illustrative embodiments for particular applications, it should be understood that the present invention is not limited thereto. Those having ordinary skill in the art and access to the teachings provided herein will recognize additional modifications, applications, and embodiments within the scope thereof and additional fields in which the invention would be of significant utility without undue experimentation. Thus, the scope of the invention should be determined by the appended claims and their legal equivalents, rather than by the examples given.

WHAT IS CLAIMED IS:

1. A system comprising:

an array of fibers arranged in a structure providing precise positioning of the fibers; and

an array of non-rod shaped optical elements, each optical element corresponding to a fiber, said array of non-rod shaped optical elements being integral with said array of fibers.

2. The system of claim 1, wherein said array of non-rod shaped optical elements is a unitary element.

3. The system of claim 1, wherein said non-rod shaped optical elements are lithographically created.

4. The system of claim 1, wherein said array of fibers and said array of non-rod shaped optical elements are two-dimensional arrays.

5. The system of claim 4, wherein one of said array of fibers and said array of non-rod shaped optical elements is a deconstructed two-dimensional array and another of said array of fibers and said array of non-rod shaped optical elements is an integrated two-dimensional array.

6. The system of claim 1, further comprising a spacer between said array of non-rod shaped optical elements and said array of fibers.

7. The system of claim 6, wherein said spacer is hollow in regions through which light is to pass between said array of non-rod shaped elements and said array of fibers.

8. The system of claim 6, wherein said spacer is transparent to wavelengths of

interest through which light is to pass between said array of non-rod shaped elements and said array of fibers.

9. The system of claim 1, wherein endfaces of fibers in said array of fibers are angled and a cross-section of non-rod shaped optical elements is matched to a cross-section of the endfaces.

10. The system of claim 2, wherein endfaces of fibers in said array of fibers are angled and the unitary element of optical elements includes an angled face to match the fiber endfaces at an interface therebetween.

11. The system of claim 10, wherein a face of the unitary element opposite the interface is parallel to the angled face.

12. The system of claim 10, wherein a face of the unitary element opposite the interface is orthogonal to a fiber axis.

13. The system of claim 1, wherein endfaces of fibers in said array of fibers are angled and said non-rod shaped optical elements reduces tilt in light output from said endfaces.

14. The system of claim 1, wherein endfaces of fibers in said array of fibers are angled and the system further comprises at least one support structure on at least one of a top and a bottom of said array of fibers, said support structure providing a mount for said non-rod shaped optical elements.

15. The system of claim 14, wherein said non-rod shaped optical elements are integrated into a unitary element, both faces of said unitary element being substantially orthogonal to a central axis of the system.

16. The system of claim 1, wherein said structure comprises a plurality of V-grooves, each V-groove receiving a corresponding fiber.

17. The system of claim 14, further comprising alignment features on a substrate supporting said array of non-rod shaped optical elements, said alignment features to be aligned with corresponding V-grooves of wherein said array of fibers and said array of non-rod shaped optical elements are two-dimensional arrays.

18. The system of claim 1, further comprising alignment marks positioned in at least one peripheral non-rod shaped optical element of said array of non-rod shaped optical elements.

19. The system of claim 1, wherein endfaces of fibers in said array of fibers are angled and said array of non-rod shaped optical elements include an anamorphic optical element.

20. The system of claim 1, wherein said anamorphic optical elements reduces tilt with respect to the fiber endface.

21. The system of claim 1, wherein said structure is a lithographically formed plurality of holes into which said array of fibers are inserted.

22. The system of claim 21, wherein said lithographically formed plurality of holes is in a polymer film deposited on a surface of a substrate.

23. The system of claim 2, wherein said unitary element includes a plurality of substrates bonded together.

24. The system of claim 1, wherein said array of optical elements includes lithographically created alignment features.

25. The system of claim 24, wherein lithographically created alignment features include at least one of visual fiducial marks and mechanical mating structures.

26. A method of integrating an array of fibers and an array of non-rod shaped optical elements comprising:

positioning the array of fibers in a corresponding array of precisely positioned housing features in a structure; and

aligning and bonding the array of non-rod shaped optical elements to the array of fibers.

27. The method of claim 26, providing an gap between the array of fibers and the array of non-rod shaped optical elements are two-dimensional arrays.

28. The method of claim 26, wherein providing includes inserting a spacer between the array of fibers and the array of non-rod shaped optical elements.

29. The method of claim 26, further comprising arranging the array of fibers and the array of non-rod shaped optical elements in two-dimensions.

30. The method of claim 29, wherein at least one of the array of fibers and the array of non-rod shaped optical elements comprises at least two one-dimensional arrays.

31. The method of claim 26, wherein said aligning includes forming passive alignment features on the array of non-rod shaped optical elements and aligning passive alignment features to the precisely positioned housing features.

32. The method of claim 26, further comprising, before said aligning, creating the array of non-rod shaped optical elements lithographically.

33. The method of claim 26, further comprising, before said aligning, creating non-rod shaped optical elements on a wafer and dicing the wafer to form the array of non-rod shaped optical elements.

34. The method of claim 32, further comprising, before said aligning, lithographically creating alignment features on the array of non-rod shaped optical elements.

FIG. 1A

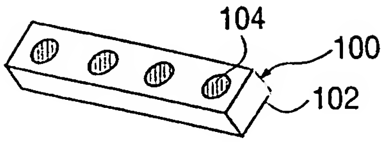


FIG. 1B

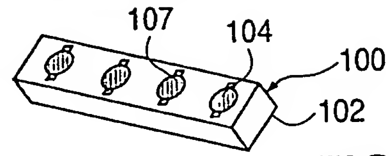


FIG. 1C

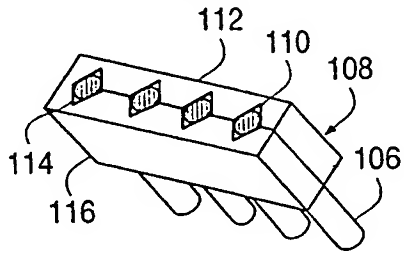


FIG. 1D

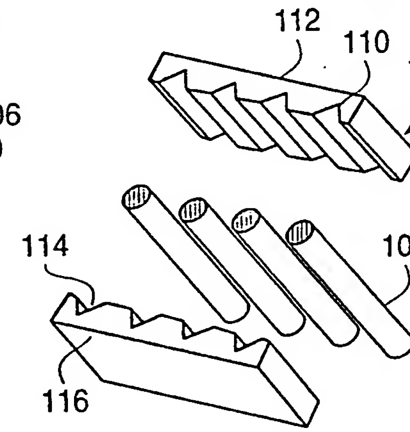


FIG. 1E

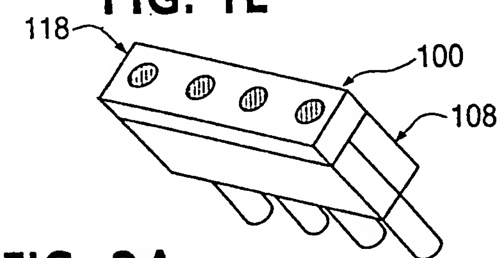


FIG. 2A

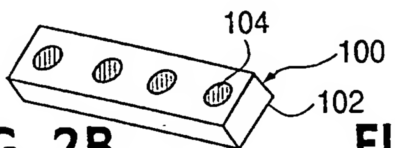


FIG. 2B

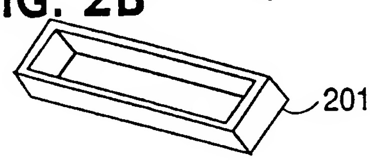


FIG. 2C

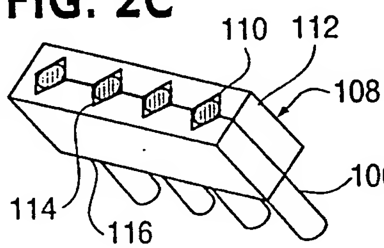


FIG. 2D

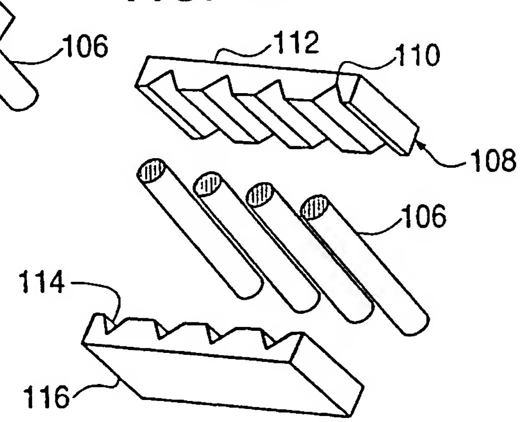


FIG. 2E

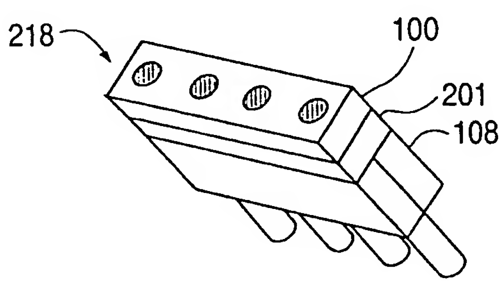


FIG. 3A

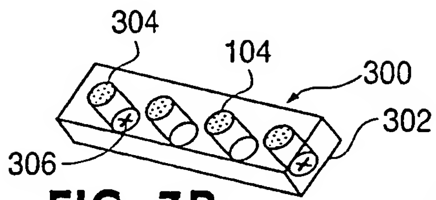


FIG. 3B

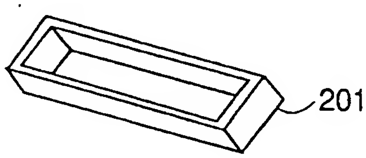


FIG. 3C

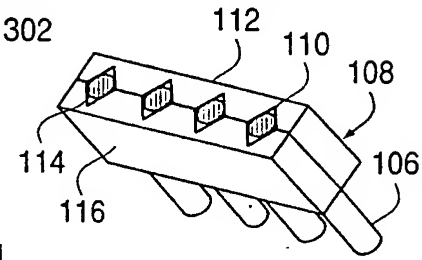


FIG. 3D

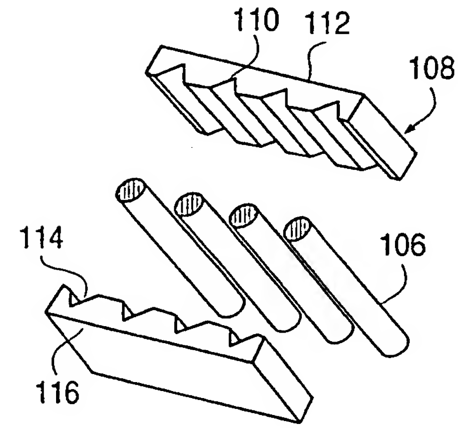


FIG. 3E

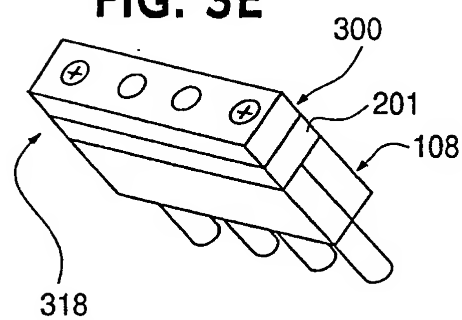


FIG. 4A

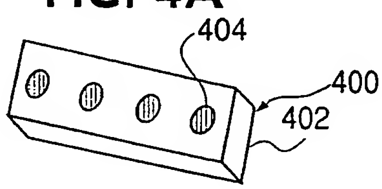


FIG. 4B

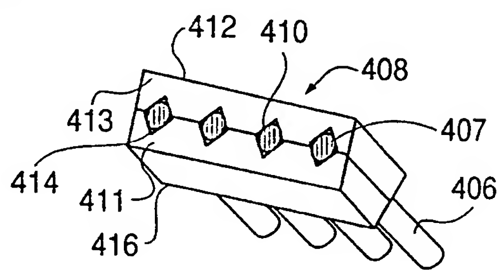


FIG. 4C

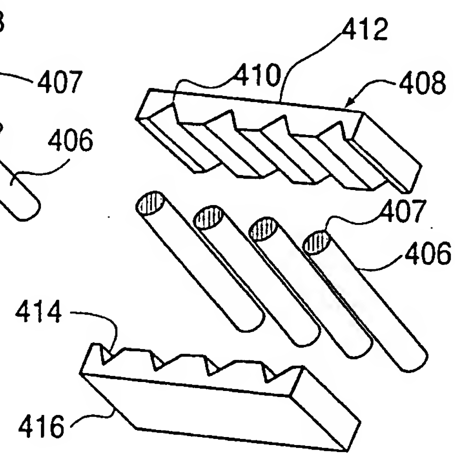


FIG. 4D

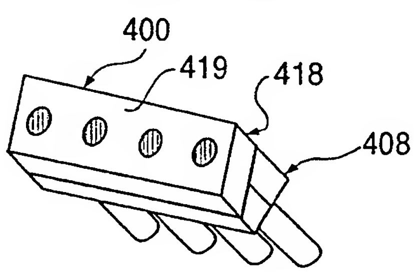


FIG. 4E

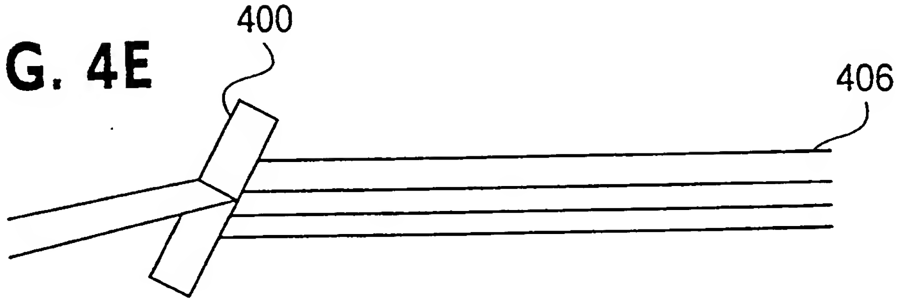


FIG. 4F

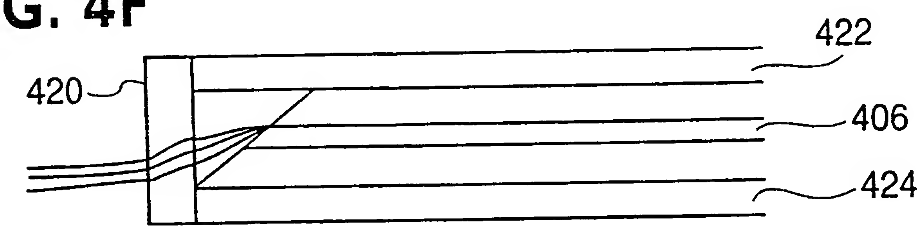


FIG. 4G

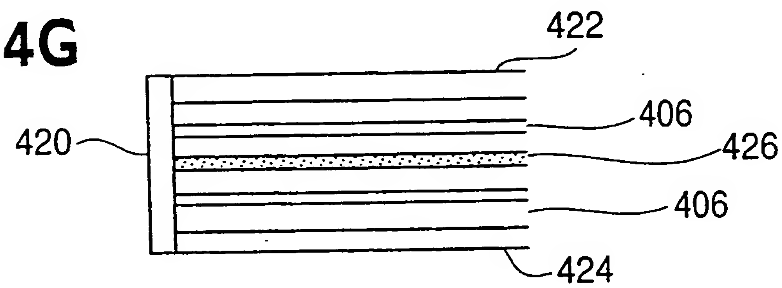


FIG. 4H

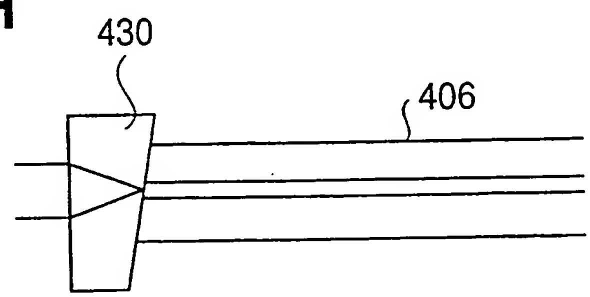


FIG. 5A

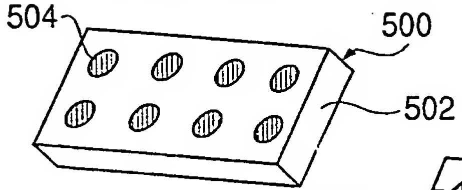


FIG. 5B

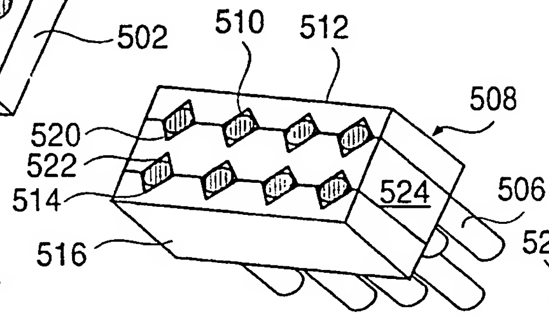


FIG. 5C

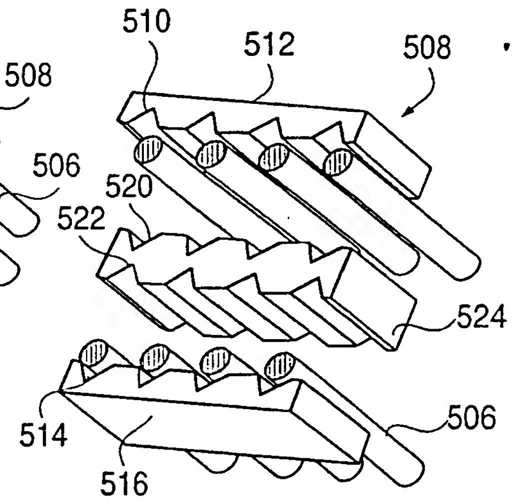


FIG. 5D

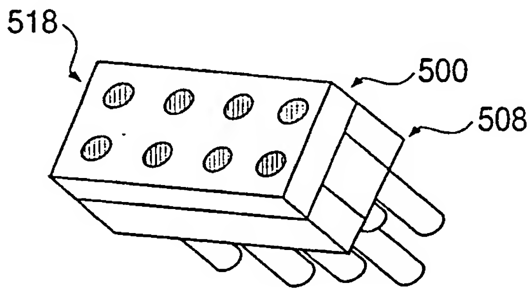


FIG. 6A

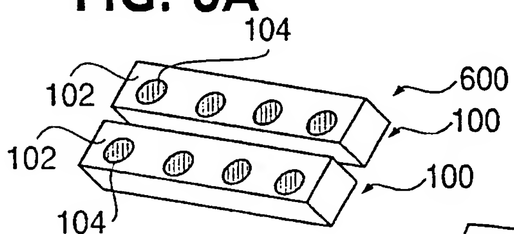


FIG. 6B

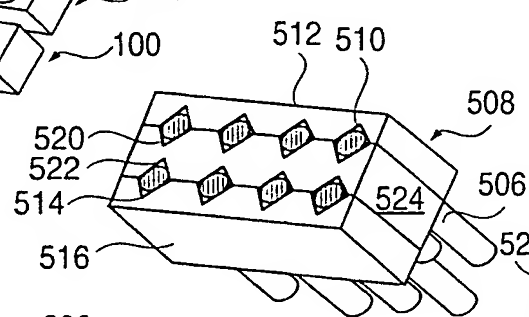


FIG. 6C

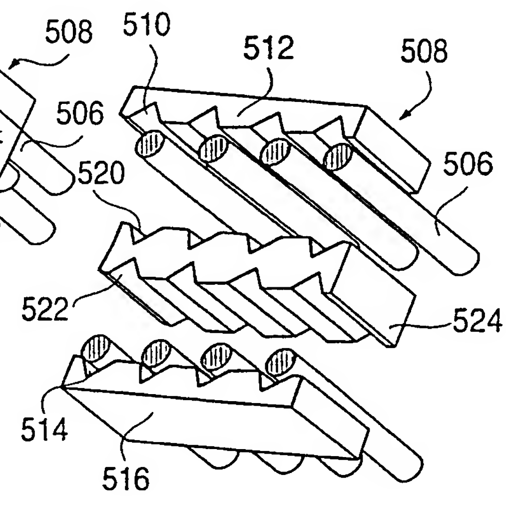


FIG. 6D

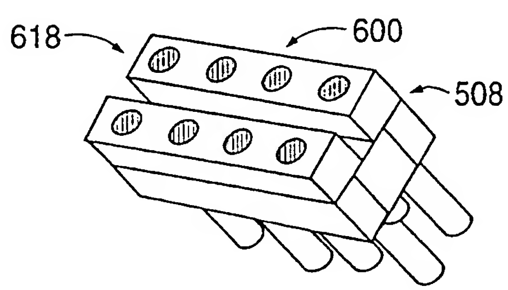


FIG. 7A

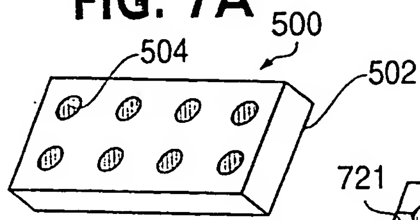


FIG. 7B

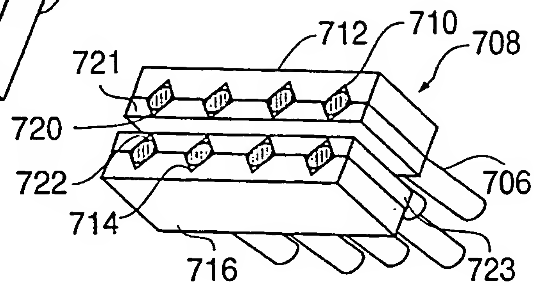


FIG. 7C

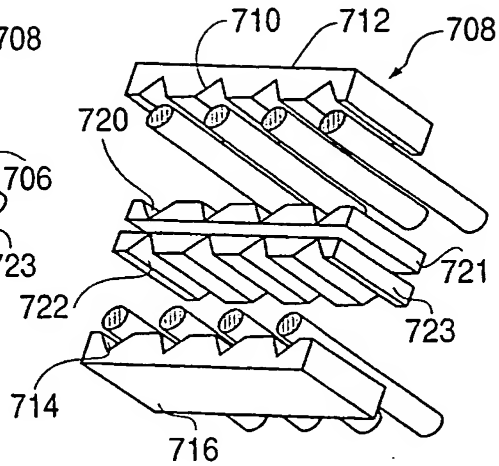


FIG. 7D

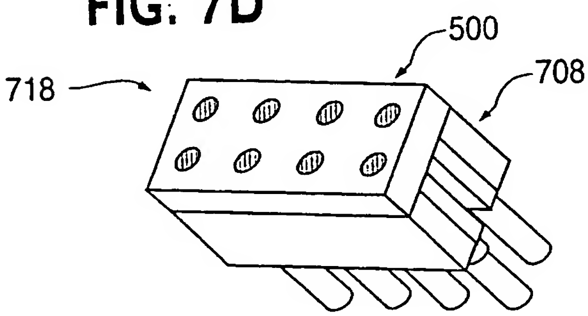


FIG. 8A

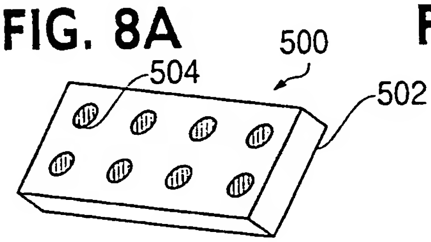


FIG. 8B

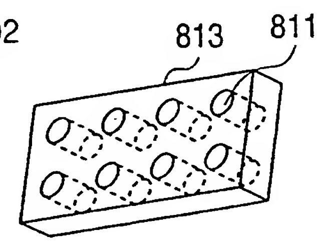


FIG. 8C

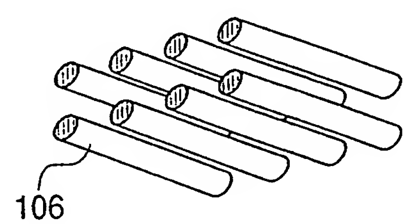


FIG. 8D

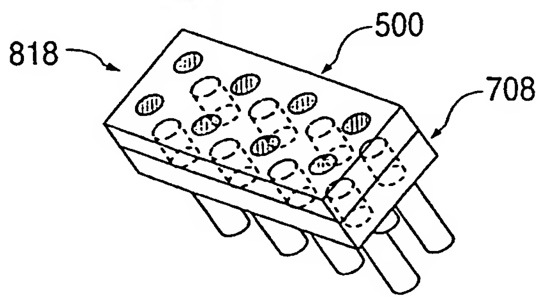


FIG. 9A

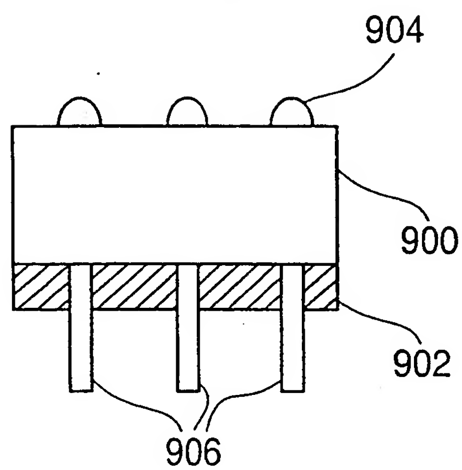
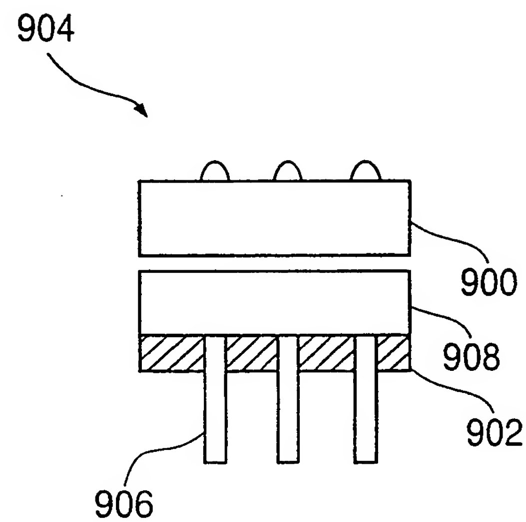


FIG. 9B



INTERNATIONAL SEARCH REPORT

Inter. ›nal Application No
PCT/US 00/30431

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B6/38 G02B6/42 G02B6/32

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

PAJ, EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 014, no. 345 (P-1083), 26 July 1990 (1990-07-26) -& JP 02 123301 A (NIPPON SHEET GLASS CO LTD;OTHERS: 01), 10 May 1990 (1990-05-10) abstract; figures 1,2	1-4,21, 22,26, 29,32,33
X	PATENT ABSTRACTS OF JAPAN vol. 017, no. 428 (P-1588), 9 August 1993 (1993-08-09) & JP 05 088049 A (FUJITSU LTD), 9 April 1993 (1993-04-09) abstract	1,2,4,6, 8,23, 26-29
X Y	US 5 241 612 A (IWAMA TAKEO) 31 August 1993 (1993-08-31) the whole document	1,2,6-8, 26-28 9-15,17, 19,20

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
3 May 2001	16/05/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Lord, R

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INTERNATIONAL SEARCH REPORT

Inter. ›nal Application No
PCT/US 00/30431

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	H. HAN ET AL: "Integration of Silicon Bench with Micro Optics" SPIE CONFERENCE ON PHOTONICS PACKAGING AND INTEGRATION, vol. 3631, January 1999 (1999-01), pages 234-243, XP000995170 San Jose, California page 236 -page 237 page 239 -page 240	1-3,16, 26,32,33
X	PATENT ABSTRACTS OF JAPAN vol. 1996, no. 07, 31 July 1996 (1996-07-31) & JP 08 075950 A (RICOH CO LTD), 22 March 1996 (1996-03-22) abstract	1,2,16, 24-26, 31,33,34
X	PATENT ABSTRACTS OF JAPAN vol. 1996, no. 03, 29 March 1996 (1996-03-29) -& JP 07 311320 A (HITACHI CABLE LTD;OTHERS: 01), 28 November 1995 (1995-11-28) abstract	1-3, 24-27, 31,33,34
Y		17,18
X	EP 0 619 505 A (NGK INSULATORS LTD) 12 October 1994 (1994-10-12) column 6, line 32 - line 37; figure 5 column 7, line 39 -column 8, line 34; figures 9-13	1,2,4,5, 16,26, 30,32
Y	EP 0 525 433 A (SIEMENS AG) 3 February 1993 (1993-02-03) the whole document	9-15, 17-20
Y	PATENT ABSTRACTS OF JAPAN vol. 018, no. 402 (P-1777), 27 July 1994 (1994-07-27) & JP 06 118283 A (RICOH CO LTD), 28 April 1994 (1994-04-28) abstract	14
Y	PATENT ABSTRACTS OF JAPAN vol. 017, no. 695 (E-1480), 20 December 1993 (1993-12-20) & JP 05 236216 A (RICOH CO LTD), 10 September 1993 (1993-09-10) abstract	19,20

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 00/30431

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 02123301 A	10-05-1990	JP 2719804 B	25-02-1998
JP 05088049 A	09-04-1993	NONE	
US 5241612 A	31-08-1993	JP 5072444 A	26-03-1993
JP 08075950 A	22-03-1996	NONE	
JP 07311320 A	28-11-1995	NONE	
EP 0619505 A	12-10-1994	JP 7005341 A	10-01-1995
		DE 69421432 D	09-12-1999
		DE 69421432 T	04-05-2000
		US 5446815 A	29-08-1995
EP 0525433 A	03-02-1993	NONE	
JP 06118283 A	28-04-1994	JP 3136205 B	19-02-2001
JP 05236216 A	10-09-1993	NONE	

Form PCT/ISA/210 (patent family annex) (July 1992)